CHAPTER 3

INDEX PROPERTIES OF SOIL

الخواص التبويبية للتربة هى تلك الخواص التى تستخدم لتقسيم التربة الى مجموعات لها صفات هندسية مشتركة , وعند إقامة مشروع تتحدد الخواص التبويبية لطبقات التربة المؤثرة فى المشروع والمجموعات التى تنتمى اليها هذه الطبقات , وبالتالى يمكن تقدير صفاتها الهندسية التى تلزم لدراسة المشروع.

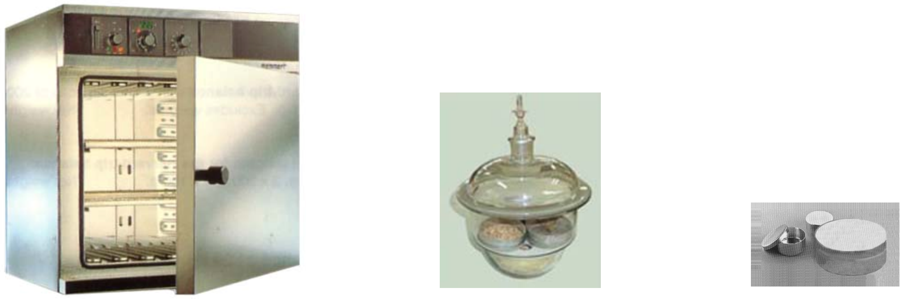
In order to relate soil behavior to its physical properties, it is convenient to have standard procedures for testing and reporting of results. This Chapter introduces constituents and definitions for index properties for soil constituents and soil mass.

3.1 Water content محتوى الرطوبة

تعتمد مقاومة التربة – خاصة الطميية والطينية – على محتوى الرطوبة بها. فتقل المقاومة مع زيادة محتوى الرطوبة وتزيد مع نقصها. لذلك يتحتم دائما تحديد محتوى الرطوبة للتربة كخطوة أولية لمعرفة صفاتها الميكانيكية.

Water content can be determined by different method. The most accurate and practical method is the oven drying method. This method is used in the laboratory.

A specimen of soil is weighed, kept in a clean container of know weight, and put in a thermostatically controlled oven with interior of non-corroding material to maintain the temperature between 105 and 110^{o} C, Fig. 3.1. Complete drying takes about 24 hours, sometimes less. The weight of the dry specimen is obtained. Notice that temperature higher than 110^{o} C may break the crystalline structure of clay particles,



فرن تجفيف العينات

مجفف واقى من الرطوبة

علب لوضع عينات التربة

Fig. 3.1 Laboratory apparatus used for water content determination

resulting in the loss of chemically bound structural water. For highly organic soils, such as peat, a lower temperature of about 60^{o} C is preferable to prevent oxidation of the organic matter. Certain soils contain gypsum which on heating losses its water of crystallization. In such case the sample is dried at no more than 80^{o} C.

The water content is calculated from the following expression:

$$w\,(\%) = \frac{W_2 - W_3}{W_3 - W_1} \times 100 \qquad \text{.. .. .. (3.1)}$$

where:

W_1 = weight of container
$W_{٢}$ = weight of container + wet soil
$W_{٣}$ = weight of container + dry soil

3.2 Specific gravity الوزن النوعى

يمكن معرفة الوزن النوعى للمركبات من مبادئ علوم الكيمياء والفيزياء. فمثلا الرمل السيليسى "النظيف" عبارة عن ثانى اكسيد السيليكون (SiO_2) ووزنه النوعى ٢,٦٥. ولكن نظراً لأن التربة تتكون من مركبات متنوعة , وقد تحتوى على نسبة من أكاسيد المعادن المختلفة كالحديد والمنجنيز وغيرها , فإنه يلزم لإجراء الحسابات الخاصة بالتربة تعيين الوزن النوعى للتربة معمليا.

The specific gravity of soil is determined accurately using the density bottle (50 cm^3) which is suitable for types of soil, Fig. 3.2.

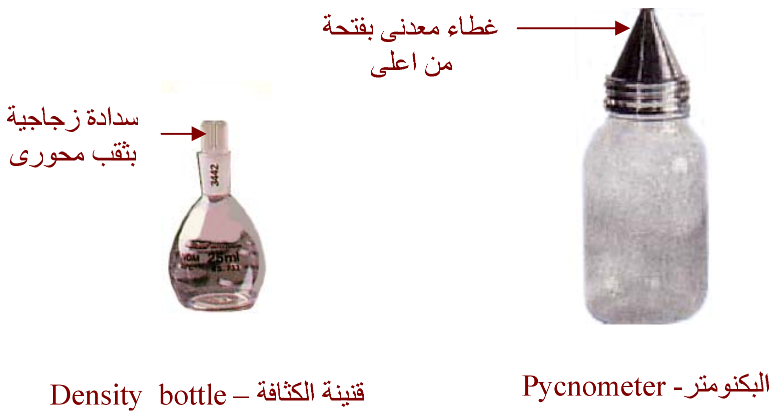


Fig. 3.2 Laboratory apparatus used for determining the specific gravity of soil

The weight (w_1) of an empty dry bottle is first determined. A sample of oven dried soil is cooled in a desiccators and put into the bottle. The weight (w_2) of bottle and soil is determined. The bottle is then filled gradually with distilled water, removing the entrapped air (الهواء المحبوس) either by applying vacuum, shaking the bottle, or gently heating it. The weight (w_3) of the bottle, soil and water is obtained. The bottle is then emptied completely, washed and filled with water then weighed (w_4).

From Fig. 3.3:

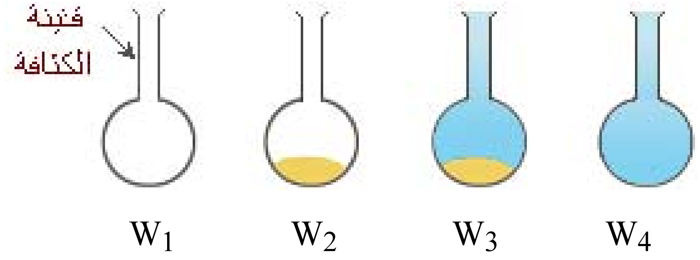


Fig. 3.3 Determination of the specific gravity of soil

$W_2 - W_1$ = weight of soil

$W_3 - W_4$ = weight of soil – weight of water having equal volume of soil.

Then:

$$G_s = \frac{(W_1 - W_2)}{(W_2 - W_1) - (W_3 - W_4)} \gamma_w \qquad \text{.. .. ..} \ (3.2)$$

For coarse grained soil the pycnometer is used instead of the density bottle. Its capacity is about 900 cm^3, the test procedure is similar to that described above, except that the removal of entrapped air can be done by shaking the pycnometer without having to use vacuum or heat. Also, a balance of 1 gm accuracy can be used.

3.3 Particle size distribution التوزيع الحبيبى (التدرج)

التدرج من أهم خواص التربة خاصة الزلطية والرملية (التربة الخشنة) ويفيد معرفته فى تقييم التربة لأعمال إنشاء الأساسات وأسلوب حفر الأنفاق وتقدير معدل تسرب المياه فى التربة وغيرها من التطبيقات العملية.

In general, a soil may contain both coarse and fine grained particles. The particle size distribution of the coarse portion can be obtained by sieving, whereas the particles distribution of fine portion is obtained by sedimentation analysis.

إذا احتوت التربة الخشنة على طمى وطين (تربة ناعمة) فيلزم "غسل" التربة على منخل مقاس ٢٠٠ (٠.٠٧٥ مم) للتخلص من الطمى والطين ، ثم وزن المتبقى بعد تجفيفه لحساب نسبتهما مجمعة , ثم نخل التربة المتبقية على المناخل الكبيرة لمعرفة تدرج محتواها من رمل وزلط .

3.3.1 Sieve Analysis التحليل المنخلى

The sieves used for the analysis are commonly:

Sieve No.	Aperture Mm	Sieve No.	Aperture Mm	Sieve No.	Aperture Mm
2	50.8	8	2.38	70	0.21
1 1/2	38.1	16	1.19	100	0.14
3/4	19.05	30	0.595	200	0.074
3/8	9.52	40	0.42	230	0.063
4	4.76	50	0.297		

Sieving is performed by arranging the various sieves one over the other in order of their mesh opening, the largest aperture sieve being placed at the top and the smallest aperture sieve is placed at the bottom. A receiver is kept at the bottom, and a cover is placed at the top. The soil sample is put on the top sieve and the sieves are put on a sieve shaking machine, Fig. 3.4, for about 10 minutes. The portion of soil sample retained on each sieve is weighed. Percentage retained and percentage passing are calculate. The resulting values are plotted on a semi-log scale.

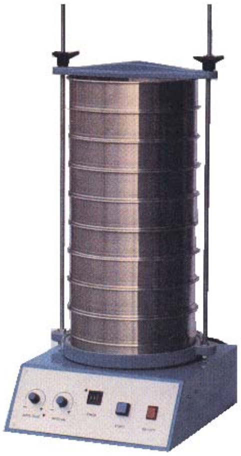


Fig. 3.4 Set of sieves placed on a shaker

3.3.2 Sedimentation Analysis

لاحظ أن التربة المارة من المنخل مقاس ٢٠٠ لا تُرى حبيباتها بالعين المجردة أو العدسة العادية , ويلزم لرؤية حبيبات الطمى استخدام الميكروسكوب الضوئى . ولرؤية حبيبات الطين فيلزم استخدام الميكروسكوب الأليكترونى . ويتحدد تدرج التربة الناعمة باجراء تجربة الترسيب .

(A) Theory:

In the sedimentation analysis, or wet analysis, the soil fraction finer than 0.075 mm is kept in suspension in a liquid medium, usually water. The analysis is based on Stoke 's law:

$$v = \frac{2}{9} r^2 \frac{G_S - \gamma_w}{\eta} \qquad \text{.. .. .. (3.3)}$$

where:

v = terminal velocity of settling sphere (cm/sec)
r = radius of sphere (cm)
η = viscosity of water (gm.sec/cm^2)
= μ/g (μ in poise "dyne.sec/cm^2", g in cm/sec^2)

Soil particles are assumed to be spherical having specific gravity (G_s). Taking D = 2 r (where r is in mm), and γ_w= 1:

$$v = \frac{1}{18} \times \left(\frac{D}{10}\right)^2 \times \frac{G_s - 1}{\eta} \qquad \text{.. .. .. (3.4)}$$

If a particle with diameter (D - mm) falls from a height (H_e – cm) in time (t – min):

$$v = \frac{H_e}{60\ t} \quad \text{(cm/sec)} \qquad \text{.. .. .. (3.5)}$$

From Equ. 3.4:

$$D = \sqrt{\frac{30\,\eta}{G_s - 1}}\ \sqrt{\frac{H_e}{t}} \qquad \text{.. .. .. (3.6)}$$

Table 3.2 gives the values of (μ) for different temperatures.

Table 3.2 Water viscosity at different temperatures

Temp. C	μ Poise	Temp. C	μ Poise	Temp. C	μ Poise	Temp. C	μ Poise	Temp. C	μ Poise
16	0.01116	21	0.00984	26	0.00875	31	0.00783	36	0.00706
17	0.01088	22	0.00961	27	0.00855	32	0.00767	37	0.00692
18	0.01060	23	0.00938	28	0.00836	33	0.00751	38	0.00679
19	0.01034	24	0.00916	29	0.00818	34	0.00736	39	0.00666
20	0.01009	25	0.00896	30	0.00800	35	0.00721	40	0.00654

The sedimentation process consists of mixing an amount of dry soil passing sieve No. 200 (0.075 mm) with distilled water in a jar. A suitable amount of dispersing agent (عامل مبعثر), usually sodium hexametaphosphate, is added. At the beginning of the sedimentation test, soil particles are uniformly distributed throughout the suspension (المعلق). After a time (t) , if a specimen is taken from a depth (H_e) , the largest diameter (D) in the specimen can be determined from Equ. 3.6. This diameter is finer than those which have already settled.

To calculate the percentage finer than this diameter (N), let (W_D) be the weight of the particles finer than the diameter (D) in unit volume of the suspension. Then:

$$N = \frac{W_D}{\left(\frac{W_d}{V}\right)} \times 100 \qquad \text{.. .. .. (3.6)}$$

where: Wd = Total weight of all particles in suspension
V = Volume of suspension.

Different particle diameters (D) and corresponding percentage finer (N) are calculated for successive (متتابع) time intervals, hence, the particles size distribution can be obtained. The sedimentation analysis is done either by using a pipette or a hydrometer.

(B) Pretreatment of soil :

Before the dry soil is made into suspension a treatment is carried out in order to:

(i) Oxidize the organic matter, if it exceeds 2 % of the weight of the dry soil.
(ii) Dissolve insoluble calcium compounds.

Details of these procedures are given in the laboratory notes.

(C) Dispersion of soil :

Dispersion is necessary in order to separate soil particles from each other and avoid clogging to take place before and during the sedimentation.

(D) Pipette method :

The soil suspension is put into a 500 cm^3 flask. Samples, 10 cm^3 each , are drawn from a depth (H_e) of 10 cm at various time intervals. The recommended time intervals are 0.5, 1,2,4,8,15,30 min. and 1,2,4,8 and 24 hours. Each sample is transferred into a suitable bottle and dried in the oven. The weight (W_D) of soilds per 1 cm^3 of suspension is thus found by taking the dry weight and dividing it by 10.

The percentage finer is calculated from the following expression :

$$N = \frac{W_D - \frac{W_1}{V}}{\left(\frac{W_d}{V}\right)} \times 100 \qquad \text{.. .. .. (3.7)}$$

where: W_1 = weight of dispersing agent present in the total suspension of volume V (500 cm^3).

The corresponding diameters (D) to which the values of (N) are calculated are obtained from Equ. 3.5. The pipette method is very simple but it requires time and very accurate weighing. This makes the hydrometer analysis more convenient for the laboratory routine tests.

(E) The hydrometer method: طريقة الهيدرومتر

In the hydrometer analysis (W_D) is computed indirectly by reading the density of soil suspension at a depth (H_e) at various time intervals. (H_e) will differ with time and therefore, it is necessary to calibrate the hydrometer, Fig. 3.5, in order to find the relation between the density of the hydrometer and (H_e).

Fig. 3.5 Hydrometer used in sedimentation analysis

(i) Calibration of hydrometer:

Fig. 3.6 shows the hydrometer scale. The reading on the hydrometer stem gives the density of the soil suspension situated at the center of bulb at time (t). The hydrometer readings are recorded after 1 and multiplying by 1000, i.e. a reading of 30 indicates a density of 1.030 gm/cm.

Let (H) be the height in cm between any hydrometer readings (R_h) and the neck, and (h) the weight of bulb. When the hydrometer is immersed in the jar , water level at (a) rises to (a_1). The rise is equal to V_h / A, where (V_h) is the volume of hydrometer and (A) the cross sectional area of jar. Similary, (b) rises to (b_1), and the rise is equal to V_h/(2A). Therefore:

$$H_e = H + h/2 + V_h/(2\,A) - V_h/A$$

i.e. $$H_e = H + (h - V_h/A)/2 \qquad \text{.. .. .. (3.8)}$$

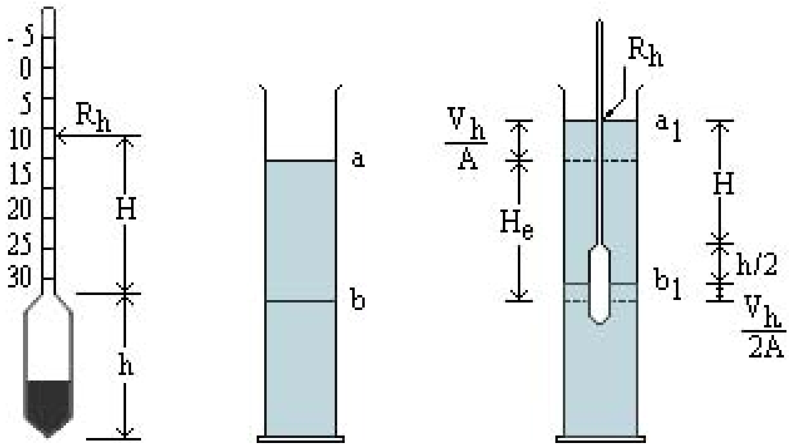


Fig. 3.6 Effect of placing the hydrometer in soil suspension

The volume of hydrometer in cm^3 is approximately equal to its weight in gm. The values of (h) can be measured corresponding to values of (R_h) and therefore, a relation between (R_h) and (H_e) can be draw as shown in Fig. 3.7.

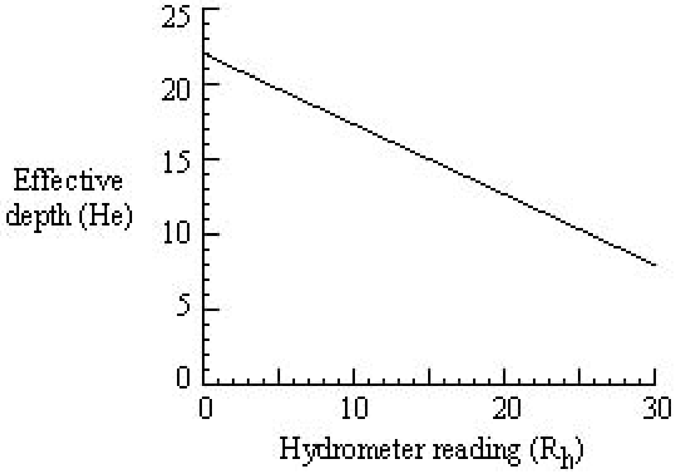


Fig. 3.7 Relation between hydrometer reading and effective depth

(ii) Test procedure:

The method of preparation of soil suspension is the same as in the pipette method. But, the volume of suspension is 1000 cm^3. The sedimentation jar is shaken with the suspension and then kept vertically while a stop watch is started. The hydrometer is slowly inserted in the jar and readings are taken at 0.5, 1, 2, 4 min., then the hydrometer is taken out, and inserted at 8, 15, 30 min, 1, 2, 4 , 8, 24 hours. Since the suspension is opaque, the readings are taken at the upper level of the meniscus, and a correction is applied.

(iii) Corrections for the hydrometer readings:

Three correction are to be applied for the hydrometer readings, the temperature correction, the meniscus correction and the dispersing agent correction.

Regarding the temperature correction (C_t), since the hydrometer is calibrated at 20^o C, if the temperature of the sediment is higher than 20^o C, the hydrometer readings will be lesser than the true values, and visa versa. The temperature correction can be obtained from Fig. 3.8.

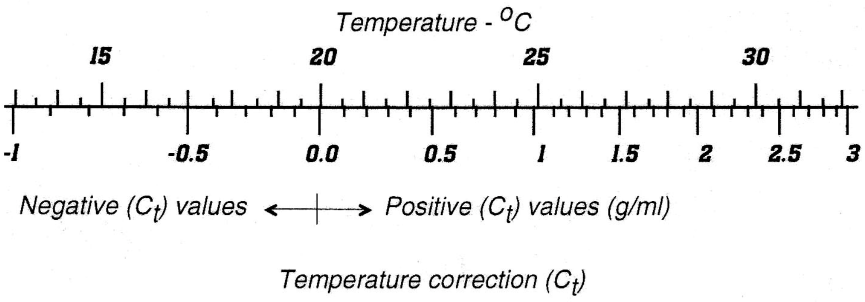


Fig. 3.8 Temperature correction chart
for hydrometers calibrated in density at 20^{o}C

Since soil suspension is opaque (معتم), the hydrometer reading is taken at the top of the meniscus. Actual reading at water surface level will be higher. Hence, the meniscus correction (C_m) is always positive. Its value is obtained by immersing (غمر) the hydrometer in a jar containing clean water, and finding the difference between the readings corresponding to the top and bottom of the meniscus.

The third correction is taken to account for the addition of the dispersion agent (C_d) which increases the density of the suspension and is always negative.

Thus the correct hydrometer reading (R) is given by:

$$R = R'_h + C_m \pm C_t - C_d \qquad .. .. (3.9)$$

where: R'_h = observed reading.

The values of (H_e) are obtained from the calibration chart, Fig. 3.7, using (R_h), where:

$$R_h = R'_h + C_m \qquad .. .. (3.10)$$

(iv) Calculation of diameter (D) and %-passing (N):

To find (D) Equ. 3.5 can be applied. Alternatively, the nomographic of the soil finer than this diameter, the weight (W_d) which is the weight of particles per 1 cm3 of the suspension, at effective height (H_e) is calculated as follows:

Since hydrometer readings have been recorder by subtracting 1 from the density and multiplying by 1000 , then we have :

$$R = (\rho - 1) \times 1000$$

i.e.

$$\rho = 1 + \frac{R}{1000} \qquad \text{.. .. .. (3.11)}$$

Now consider a unit volume (1 cm3) of suspension, at time (t), at effective depth (H_e). If (W_D) is the weight of soilds, then:

The weight of water in 1 cm^3 = $1 - W_D / G_s$

It follows that the total weight of 1 cm^3 of suspension (i.e. density of suspension):

$$\rho = 1 - W_D / G_S + W_D$$

Substituting for ρ from Equ. 3.11:

$$1 + R/1000 = 1 - W_D / G_S + W_D$$

Then : $W_D = \frac{R}{1000} \times \left(\frac{G_S}{G_S - 1} \right)$

Substituting by (W_D) in Equ. 3.6:

$$N = \frac{R}{1000} \times \left(\frac{G_S}{G_S - 1} \right) \times \frac{1}{\frac{W_d}{V}} \times 100$$

Taking V = 1000 cm^3 :

$$N = \frac{100\, G_S}{W_d (G_S - 1)} \times R \qquad \text{.. .. .. (3.12)}$$

(v) Combined sieve and sedimentation analysis:

If (N_s) is the percentage finer than sieve No. 200, originally taken from particle size distribution analysis, and (N) is the percentage finer than (D), then:

$$N_{cum.} = N \cdot N_S \qquad \text{.. .. .. (3.13)}$$

where: $N_{cum.}$ = Cumulative percentage finer

(vi) Particle size distribution curve:

Results of particles distribution tests are plotted with the percentage finer as ordinate, and particle diameter as the abscissa. The diameter is plotted on a logarithmic scale, Fig. 3.9.

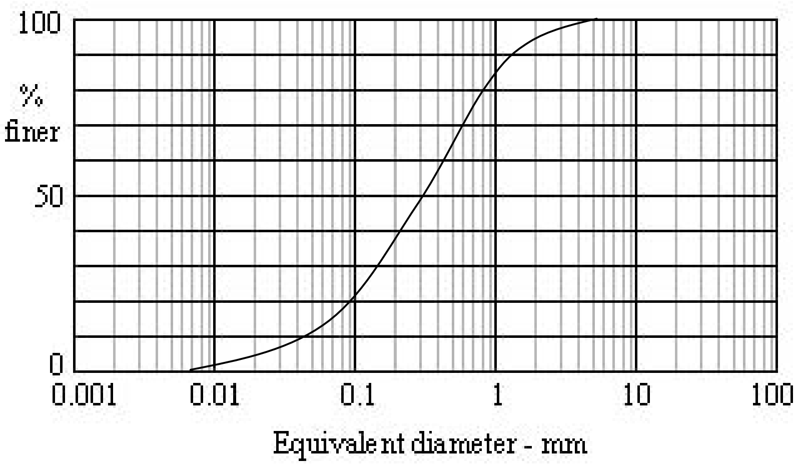


Fig. 3.9 Semi-log plot for presenting particle size distribution

A particles size distribution curve gives an idea about the type and the gradation of the soil. A soil sample may be either "well graded" or "poorly: A well graded soil contains particles of all sizes well represented, while poorly graded soil has deficiency of certain particles, or most of the particles are of about the same size, Fig. 3.10.

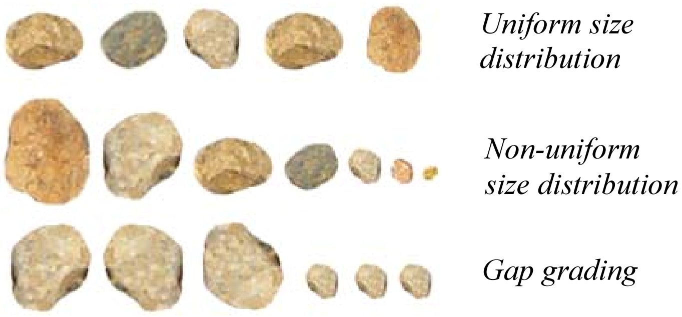


Fig. 3.10 Examples of particle size distribution

The grading curves shown in Fig. 3.11 indicates that soil (A) is well graded, and soil (B) is poorly graded.

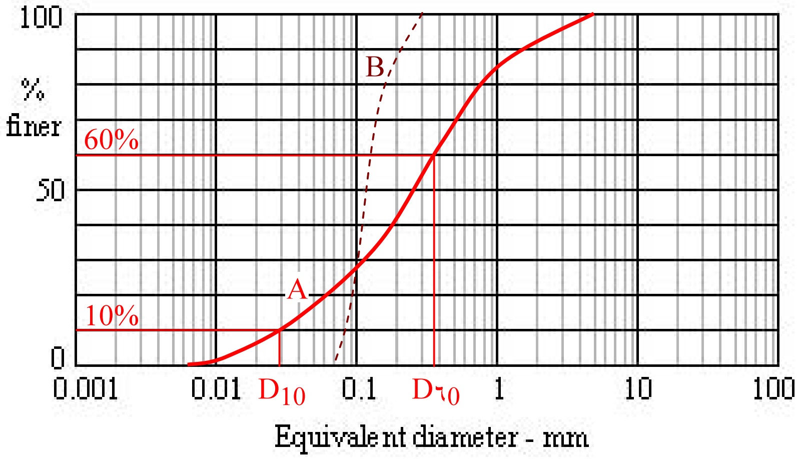


Fig. 3.11 Types of grading and determination of grading parameters

(vii) uniformity coefficient and effective diameter :

The uniformity coefficient is a measure of the particle size range, and is given by the relation:

$$U=\frac{D_{60}}{D_{10}} \qquad \text{.. .. .. (3.14)}$$

where: D_{60} = particle diameter at which 60 % of the soil is finer.

D_{10} = particle diameter at which 10 % of the soil is finer.

The particle diameter D_{60} and D_{10} are determined by drawings lines through points 60 % and 10 % on the percentage finer scale, and parallel to the abscissa, until intersection with the particle size distribution curve. Projections of these points on abscissa gives the required diameters, Fig 3.11. The diameter D_{10} is called the "effective diameter" and is used in estimating some the mechanical properties of the soil.

3.4 Consistency of soil قوام التربة

حدود القوام للتربة الطميية والطينية هما حد السيولة وحد اللدونة , ويتم تعيينهما بالتجارب المعملية بغرض معرفة مدى قابلية التربة للانضغاط والتشكل .

كلما زاد محتوى الطين فى التربة وزادت فاعاليته (التى تعتمد على معدن الطين) كلما زادت قيمة حد السيولة , وزاد المدى لمحتوى الرطوبة الذى يمكن ان تكون فية التربة فى حالة لدنة (صلصالية) , وبالتالى زادت قابلية التربة للانضغاط , وكلما اقترب محتوى الرطوبة من حد السيولة كانت التربة أضعف فى تحمل المبانى .

Consistency means the relative case with which soil can be deformed. The term is used for fine grained soils and is related to a large extent to the water content. If soil is mixed with a large quantity of water , it forms a suspension. If water is evaporated, the soil passes through various **"states of consistency"**, Fig. 3.12. These states are:

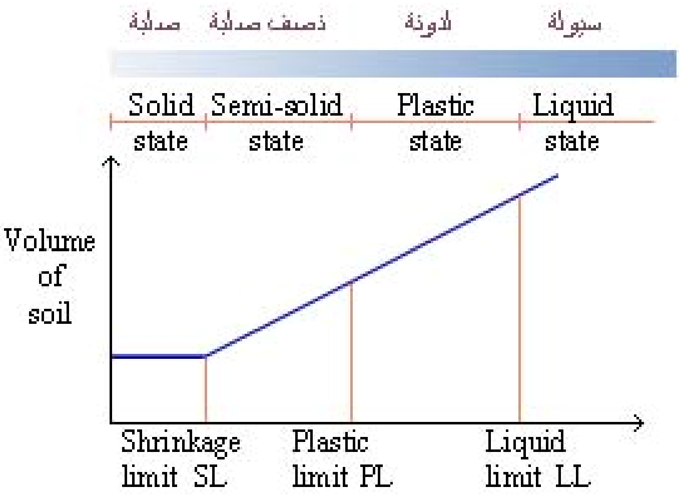


Fig. 3.12 Change of state of consistency of soil
With change of water content

(a) Liquid state (b) Plastic state
(c) Semi – solid state (d) Solid state

The boundary between these states are known as **"Atterberg limits"**, and they are water contents at which the soil changes from one state to another. The limits are:

(a) Liquid limit, (b) Plastic limit, (c) Shrinkage limit.

3.4.1 Liquid limit (LL)

The liquid limit is the water content corresponding to a limit between liquid and plastic states of consistency. It is also the minimum water content at which the soil is still in the liquid state, but has a small shearing resistance against flowing.

Determination of liquid limit: تعيين حد السيولة

The liquid limit is measured in the laboratory by using a standard apparatus (Casagrande's method), Fig. 3.13. The apparatus consists of a hard base over which a brass cup drops through a height of 1 cm. The procedure of test is summarized as follows:

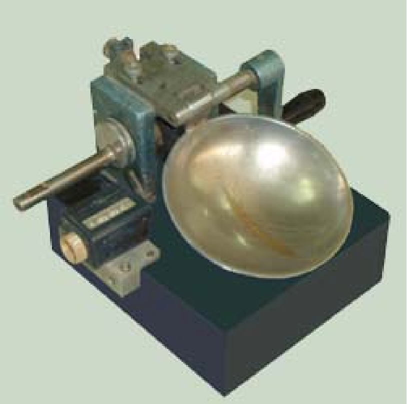


Fig. 3.13 Liquid limit test Casagrande apparatus

(a) The soil is mixed with distilled water to from a uniform paste.
(b) A portion of the paste is placed in the cup and cut with a grooving tool.
(c) The apparatus handle is rotated and the number of blows is counted until the two halves of the soil come into contact.
(d) A sample is taken near the closed groove and its water content is determined.
(e) The test is repeated with the water content changed and the corresponding number of the blows as abscissa on a logarithmic scale and the water content as ordinate, Fig. 3.14. Such a graph is a straight line. The liquid limits is obtained as water content corresponding to 25 blows.

With reference to the standard apparatus, the liquid limit is defined as the minimum water content at which a part of soil cut by the groove of standard dimensions will flow together for a distance of 1 cm under the impact of 25 blows.

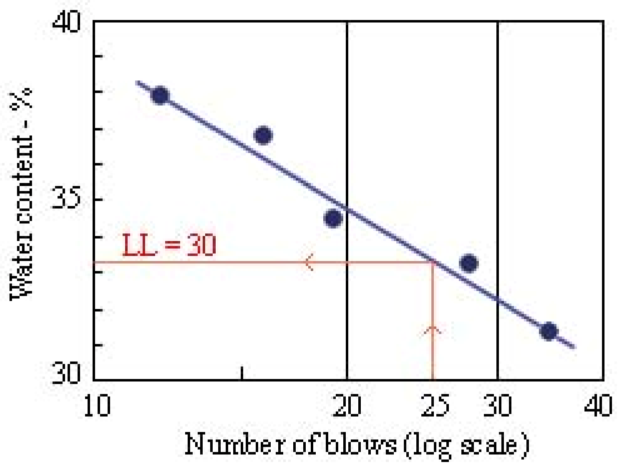


Fig. 3.14 Determination of liquid limit by Casagrande's method

3.4.2 Plastic limit (PL) حد اللدونة

The plastic limit is the water content corresponding to an arbitrary limit between the plastic and semi – solid states of consistency of a soil.

Determination of plastic limit : تعيين حد اللدونة

The procedure of test is summarized as follows:

(a) The soil is mixed with distilled water and a ball weighing 10 gm is formed.
(b) The ball is rolled between the finger and glass plate, with just sufficient pressure to role the soil mass into a thread of uniform diameter throughout its length, Fig. 3.15
(c) When a diameter of 3 mm is reached the soil is remolded again into a ball. The pressure of rolling and remolding is repeated until the thread starts just crumbling at a diameter of 3 mm .
(d) The water content of the soil thread is determined and it corresponds to the plastic limit.

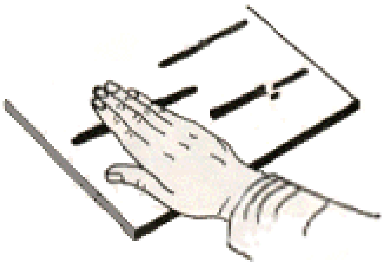


Fig. 3.15 Determination of plastic limit

3.4.3 Plasticity Index (PI) مبين اللدونة

The plasticity index indicates the range of consistency within which a soil exhibits plastic properties. It is defined as :

$$PI = LL - PL \qquad \text{.. .. .. (3.15)}$$

3.4.4 Consistency index (I_c) مبين القوام

The consistency index is defined as:

$$I_c = \frac{LL - W}{LL - PL} \qquad \text{.. .. .. (3.16)}$$

The consistency index is useful in studying the field behavior of saturated fine grained soils. If the consistency index of a soil is equal to unity, it is at the plastic limit. If (I_c) equals zero, it will be at the liquid limit.

3.4.5 Liquidity index (IL) مبين السيولة

The liquidity index is defined as:

$$I_L = \frac{w - PL}{LL - PL} \qquad \text{.. .. .. (3.17)}$$

3.4.6 Shrinkage Limit (SL) حد الأنكماش

The shrinkage limit is defined as the maximum water content at which a reduction in water content will not cause a decrease in the volume of soil. It is the lowest water content at which a soil can be saturated.

If a saturated soil, Fig. 3.16, having water content (w_1) higher than the shrinkage limit is allowed to dry, (V_1) will reduce to (V_2) at the shrinkage limit (SL) . Further reduction of volume. At complete drying, the volume is termed (V_d) which is equal to (V_2).

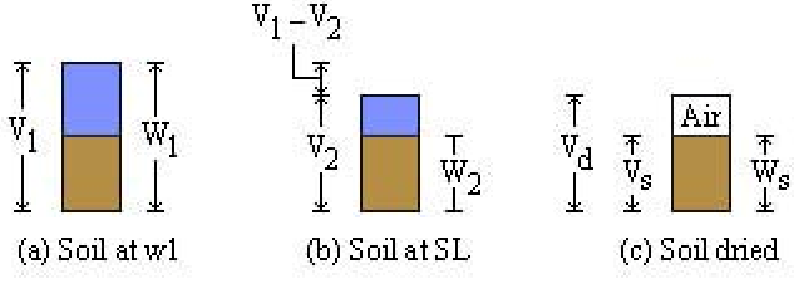


Fig. 3.16 Calculation of the shrinkage limit of soil

The shrinkage limit is therefore calculated as follows:

$$SL = \frac{(V_1 - V_2)\gamma_w}{W_s} \qquad \text{.. .. ..} \quad (3.18)$$

Determination of the shrinkage limit: تعيين حد الأنكماش

The form of Equ. 3.18 suggests the method of determining the shrinkage limit in the laboratory. The procedure of test is summarized as follows:

(a) A cylindrical container, called the shrinkage dish is used, Fig. 3.17. its volume is determined by filling it to over – flowing with mercury and removing the excess by a flat glass plate over its top and then weight the dish filled with mercury. The weight of mercury contained in the dish divided its density (13.6 gm/cm^3) gives the volume of dish.

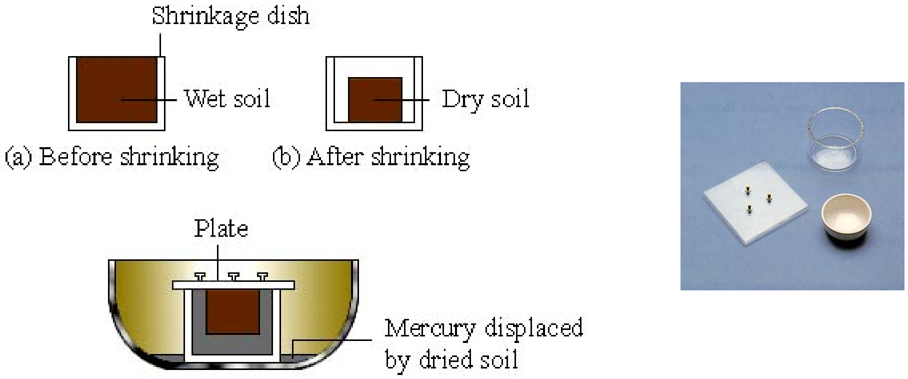


Fig. 3.17 Method of determining the volume of dry soil

(b) About 50 gm of soil passing sieve No. 40 is mixed with distilled water sufficient to fill the voids completely and to make the soil pasty enough to be placed in the shrinkage dish without air bubbles.

(c) The dish is gradually filled by putting the soil in small amounts and tapping to exclude the inclusion of air. The excess soil is removed and the dish is immediately weighted, thus the weight of the wet soil (W_1) is determined.

(d) The dish is then placed in the oven. When the soil dries it will shrink. Its weight (W_s) is determined.

(e) In order to determined the volume of dried soil (V_d), the dish is first filled with mercury and placed in evaporating dish. The dry soil is placed on the top of the mercury and pushed with a plate. The weight of the collected mercury divided by the density of mercury gives the required volume (V_d).

(f) The shrinkage limit is calculated from Equ. 3.18.

3.4.7 Alternative method for calculating the shrinkage limit

The shrinkage limit can be obtained as follows :

$$SL = \left[\left(V_d - V_s\right)\gamma_w\right] / W_s$$

i.e.

$$SL = \left(\frac{\gamma w}{\gamma d} - \frac{1}{Gs} \right) \quad \text{.. .. .. (3.19)}$$

Also, Substituting for γ_d by:

$$\gamma_d = G_s \, \gamma_w / (1 + e)$$

we get :

$$SL = \frac{e}{G_S} \quad \text{.. .. .. (3.20)}$$

3.4.8 Volumetric and linear shrinkage

The volumetric shrinkage is defined as :

$$V.S. = \frac{(V1 - Vd)}{Vd} \quad \text{.. .. .. (3.21)}$$

The linear shrinkage is the strain in one dimension of a soil mass when the water content of the soil is decreased from a given value to the shrinkage limit. It is defined as :

$$L.S. = 1 - \left(\frac{1}{V.S. + 1} \right)^{\frac{1}{3}} \quad \text{.. .. .. (3.23)}$$

بالنسبة لحد الأنكماش فقد دلت بعض الابحاث على أنه كلما قل حد الأنكماش للتربة الطينية كان ذلك مدلولاً على أن معدن الطين قابلا للأنتفاش .

The plasticity characteristics of some Egyptian soils are given in Fig. 3.18

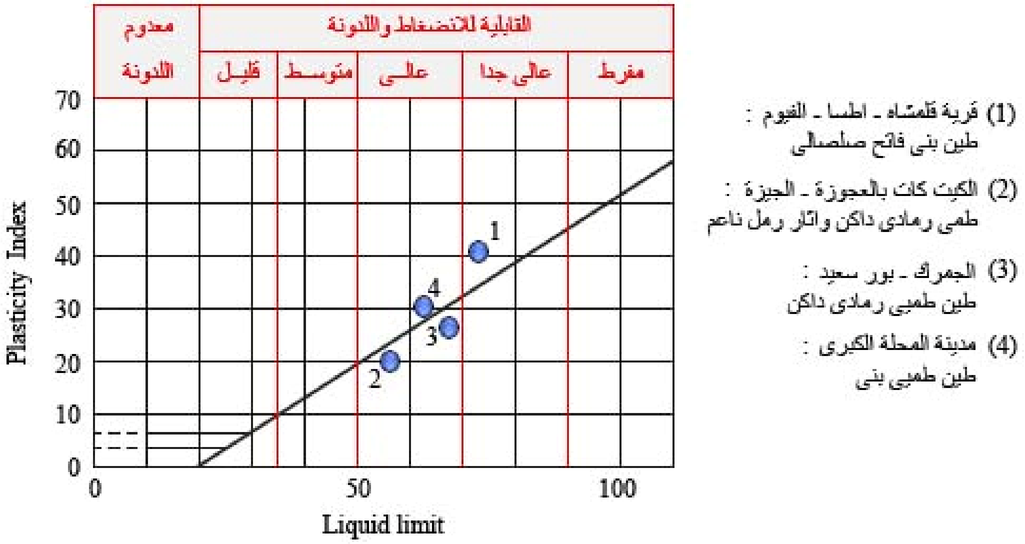


Fig. 3.18 Plasticity characteristics of some Egyptian soils

3.6 In-situ density

تعطى الكثافة الجافة على مدى مقاومة التربة باعتبار ان الحبيبات الصلبة هى مصدر "القوة" ومن الكثافة الجافة يمكن تحديد مدى تدمك التربة وكذلك تحديد نسبة الفراغات ومسامية التربة . ولهذه المعاملات تطبيقات كثيرة فى دراسات ميكانيكا التربة وهندسة الطرق.

يمكن باستخدام طريقتى الوعاء الرملى وقاطع القالب تحديد كثافة التربة الطبيعية فى طبقاتها السطحية , او كثافة التربة المدموكة مثل تربة الاحلال التى تنفذ احيانا اسفل أساسلت المبانى .

The in-situ density of a natural soil or compacted soil is determined by the following methods:

3.5.1 Sand bottle method

In this method a sand pouring cylinder, called the sand bottle, in used. The cylinder has a top cover; at the bottom it is joined to a cone. A valve is fitted between the cylinder and the cone. The cylinder is filled with sand, Fig. 3.١٩.

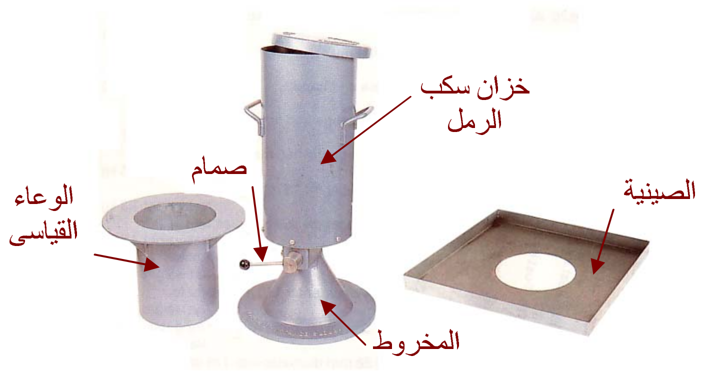


Fig. 3.19 (a)

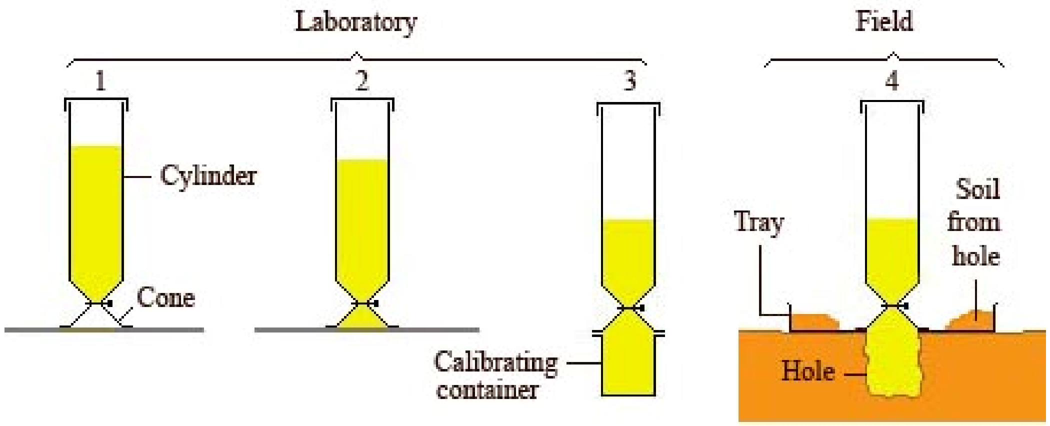


Fig. 3.19 (b)

Fig. 3.19 Procedure for determining the in-siyu density of soil

Laboratory calibration of the sand filling the cylinder:

Before using the cylinder in the field, calibration is first carried out to determine the weight of the sand filling the cone, and to determine the density of the sand falling from the cylinder .

(a) To determine the weight of sand filling the cone (W_c), the cylinder nearly filled with sand, is weighted (W_1), then placed on a flat surface. The valve is opened and the sand is allowed to fall out filling the cone. The valve is then shut and the cylinder is lifted and weighed (W_2). Then,

$$W_c = W_1 - W_2$$

(b) To determine the density of the sand filling the cylinder a standard container of known dimensions is used. The sand bottle is placed on the top of the container, and the valve is opened allowing the sand to fall in filling the container and the cone. The sand bottle is lifted and weight (W_3). The weight of the sand filling the standard container (W_t) will be:

$$W_t = W_1 – W_2 – W_3 – W_c \text{ .}$$

The density of the sand (ρ_{sand}) is obtained by dividing the weight of the sand filling the standard container by its volume.

Determination of the in-situ density:

(a) A tray having in its center a circular hole of the end of the cone, is placed at the top of the ground. A hole of approximately the same dimensions as the standard container is dug into the natural soil. The excavated soil is collected in the tray and weighed (W).

(b) The sand bottle is placed at the top of the hole and the valve is opened allowing the sand to fall out filling the hole and the cone (W_4).

(c) The weight of the sand filling the hole (W_h) will be:

$$W_h = w_1 - W_4 – W_c.$$

Therefore, the volume of the hole, or the volume of the excavated soil in the natural state, will be : $V = W_h / \rho_{sand}$.

(d) The sand in-situ density will be : $\gamma_b = W/V$

(e) The natural dry density and void ratio can be determined by taking a sample from the excavated soil and finding its natural water content, then applying the relation 2.20.

3.5.2 The Core cutter method

A core cutter consisting of a steel cutter, 10 cm diameter and about 13 cm high, together with a dolly, 2.5 cm high, Fig. 3.20, is driven into the soil using a suitable rammer. The soil is to fill the cutter and to project about 1 cm into the dolly. The cutter containing the soil is dug out of the ground; the dolly is removed and the excess soil is trimmed off. The weight of the soil in the cutter is found. By dividing it by the volume of the cutter, the bulk density is determined. The dry density can be determined as previously mentioned.

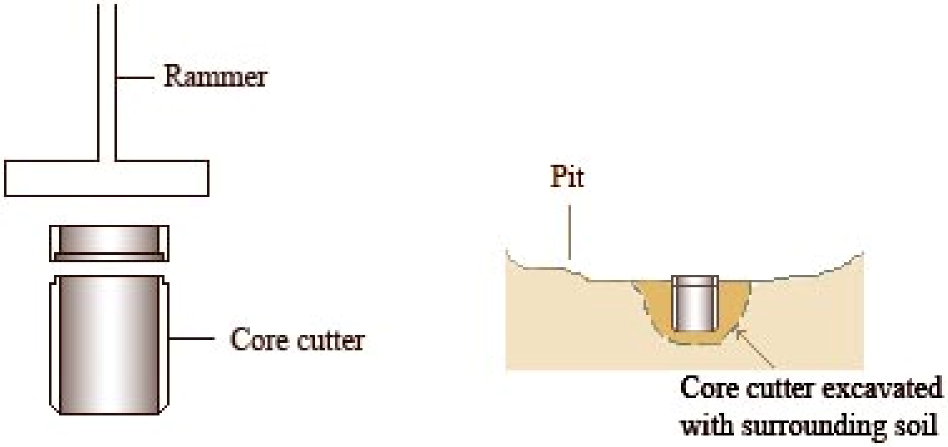


Fig. 3.20 The core cutter method

3.6 Relative density الكثافة النسبية

الكثافة النسبية مقياس لمدى تدامك أو تفكك التربة الرملية ويلزم لتحديدها خطوات معملية وحقلية . وما يتم فى العمل هو أولا سكب الرمل فى وعاء بحيث يكون مفككا الى اقصى درجة ممكنة وتحديد نسبة الفراغات , وثانيا وضعه فى وعاء يحيث يكون مدموكا الى اقصى درجة ممكنة وتحديد نسبة الفرغات المقابلة لذلك . ولا توجد طرق قياسية لتحضير الرمل المفكك او المدموك إنما يترك ذلك للتقدير الشخصى .

وبالنسبة للخطوات الحقلية اذا كانت التربة المراد تحديد كثافتها النسبية فى طبقة سطحية فيتم تحديد كثافتها فى الموقع كما سبق شرحه بطريقة الوعاء الرملى , واذا كانت التربة المراد تحديد كثافتها النسبية فى الطبقة سفلية فيتم تحديد كثافتها فى الموقع باجراء تجربة حقلية فى الجسة . ومن الكثافة الكلية للتربة فى الموقع

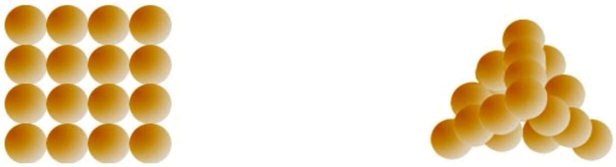
ومحتوى الرطوبة تحسب نسبة الفراغات للتربة فى الموقع .
بمعرفة اقصى وادنى نسبة فراغات للتربة ونسبة الفراغات فى
حالتها الطبيعية تحسب الكثافة النسبية .

The relative density is an index property used to describe the compactness of coarse grained soils. It is determined by knowing the natural void ratio of sand in the field, also the void ratio when the sand is replaced in its loosest state and its densest state. The relative density is defined as :

$$D_r = \frac{e_{max.} - e}{e_{max.} - e_{min.}} \qquad \text{.. .. .. (3.24)}$$

The natural of void can be obtained by using the sand bottle to determine the sand in-situ density. The values of both $e_{max.}$ and $e_{min.}$ vary according to the type of soil, its grading and grain shape.

The range of void ratio generally encountered can be calculated by considering the case of ideal spherical particles of equal size. The loosest and densest are obtained for the cubical and pyramidal types of packing, as shown in Fig. 3.2١. the corresponding maximum and minimum void ratios are 0.91 and 0.34 , respectively.



(a) Loosest packing (b) Densest packing

Fig. 3.21 Types of packing for spheres of equal size

For natural soils the values of $e_{max.}$ and $e_{min.}$ can be determined in the laboratory. For packing the soil at its loosest state, the soil is dried and allowed to fall into a container such that the free fall of the particles is about 2 cm. The densest state can be achieved by applying static, vibratory (اهتزازى) and dynamic compaction to the soil in the container. In both procedures the minimum and maximum dry densities are measured from which the corresponding $e_{max.}$ and $e_{min.}$ Are calculated. Table 3.3 gives the description of compactness of coarse grained soils according to their relative density.

Table 3.3 Compactness of coarse grained soil

Relative density %	Description of compactness	وصف درجة التدامك
< 15	Very loose	مفكك جدا
15 - 35	Loose	مفكك
35 - 65	Medium dense	متوسط الكثافة
65 - 85	Dense	كثيف
> 85	Very dense	كثيف جدا

3.7 Examples

(1) The pycnometer is used for determination of specific gravity of a sandy soil . the result are as follows:

Weight of pycnometer empty = 210 gm
Weight of pycnometer + dry soil = 515 gm
Weight of pycnometer + soil + water = 1155 gm
Weight of pycnometer filled with water = 965 gm

Find the specific gravity.

Solution:

$$G_s = \frac{W_2 - W_1}{(W_2 - W_1) - (W_3 - W_4)}$$

$$= \frac{515 - 210}{(515 - 210) - (1155 - 965)}$$

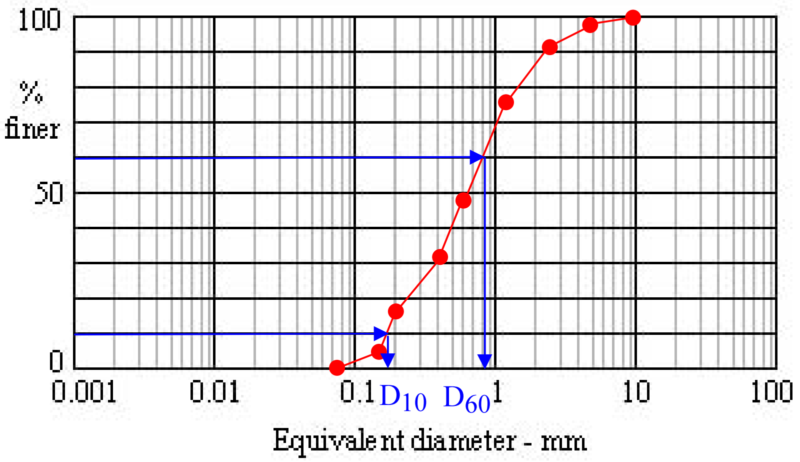
$$= 2.65$$

(2) Results of particle size distribution analysis of a soil sample weighing 2.77 kg are given. Draw the grading curve. Find the effective diameter and uniformity coefficient.

Sieve size (mm)	9.52	4.8	2.4	1.2	0.6	0.42	0.21	0.15	0.075
Weight retained (gm)	0	56	189	421	778	444	417	361	55

Solution:

Sieve Size	Weight retained	Cum. Weight retained	% retained	% finer
9.52	0	0	0	100
4.8	56	56	2	98
2.4	189	245	8.8	91.2
1.2	421	666	24	76
0.6	778	1444	52.1	47.9
0.42	444	1888	68.2	31.8
0.21	417	2305	83.2	16.8
0.15	361	2666	96.2	3.8
0.075	55	2721	98.2	1.8
Pan	49	2770	100	0



From curve :

D_{10}=0.18

D_{60}=0.83

U=0.83/0.18=6.5

(3) Results of sieving and hydrometer test are given below. Draw the particle size distribution of the soil. Find the clay, silt and sand contents. Data :

Sieve No.	Aperture mm	% finer
8	2.38	100
40	0.42	97
100	0.149	92
200	0.075	87

Hydrometer results :

$W_d = 37$ gm

$G_s = 2.7$

$C_d = 1.2$

$C_m = 0.5$

N.B. Use the hydrometer calibration given in Fig. 3.3

Date	Time	Elapsed Time (min.)	Temp. ^oC	Hydrom. Reading (R'_h)
9.12.89	10 : 00	0	17	-
		1		22.0
		2		21.5
		4		20.3
		8		18.5
		15	18	17.0
		30	18	15.1
	11 : 00	60	20	13.0
	12 : 00	120	22	10.2
	14 : 00	4 h	22	8.8
	18 : 00	8	20	6.1
10.12.89	8 : 00	22	15	4.8
11.12.89	10 : 00	48	15	4.2

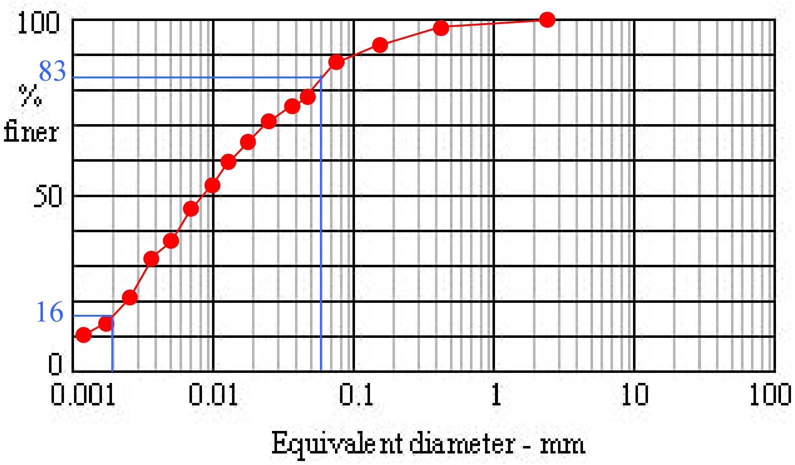
Solution:

Step No.:

1	2	3	4	5	6	7	8
R_h	He cm	μ Poise	D mm	C_t	R	N %	N' %
-	-	0.01088	-	- 0.5	-	-	-
22.5	11.875	"	0.0482	"	20.8	98.3	77.7
22.0	12.1	"	0.0344	"	20.3	87.1	75.8
20.8	12.64	"	0.0249	"	19.1	82.0	71.3
19.0	13.45	"	0.0181	"	17.3	74.3	64.6
17.5	14.125	0.01060	0.0134	- 0.34	15.96	68.5	59.6
15.6	14.98	"	0.0098	"	14.06	60.4	52.5
13.5	15.925	0.01009	0.0069	0	12.3	52.8	45.9
10.7	17.185	0.00961	0.0050	+ 0.38	9.88	42.4	36.9
9.3	17.815	"	0.0036	"	8.48	36.4	31.7
6.6	19.03	0.1009	0.0027	0	5.4	23.2	20.2
5.3	19.615	0.01116	0.0017	0.63	3.47	14.9	13.0
4.7	10.885	"	0.0012	"	2.87	12.3	10.7

Step 1: Apply Equ. 3.10
Step 2: Use Fig. 3.7
Step 3: Use Table 3.2 (divide μ by 981 to get η)
Step 4: Apply Equ. 3.6
Step 5: Use Fig. 3.8
Step 6: Apply Equ. 3.9
Step 7: Apply Equ. 3.12
Step 8: Apply Equ. 3.13

Results are plotted as shown.



From curve :

Sand content = 16 %
Silt content = 67 %
Clay content = 17 %

(4) A soil sample weighting 40 gm is pretreated, dispersed using 20 gm of a dispersing agent, then mixed in 500 cm^3 of distilled water. The sample is placed into a graduate and allowed to settle. Find the time at which the top 10 cm of the suspension will include only particles finer than 0.02 mm. If a pipette is inserted at that depth and the weight of soil solids in 1 cm^3 is found to be 0.096 gm, what will be the %-finer than 0.02 mm. Take $\eta = 0.01$ poise and $G_s = 2.7$.

Solution:

$$D = \sqrt{\frac{1800\,\eta}{G_s - 1)}}\sqrt{\frac{H_e}{60\,t}}$$

$$0.02 = \sqrt{\frac{1800\,(0.01)}{980(2.7-1)}}\sqrt{\frac{10}{60\,t}}$$

$$\therefore\ t = 4.5\ \text{min.}$$

$$N = \frac{W_D - \frac{W_1}{V}}{\frac{W_d}{V}} \times 100$$

$$\therefore\ N = \frac{0.096 - \frac{20}{500}}{\frac{40}{500}} \times 100$$

$$= 70\,\%$$

(5) The liquid and plastic limits of a soil are 68 and 25, respectively. Determine the plasticity index. If the natural water content is 40.67 %, find the consistency and liquidity indices.

Solution:

$$PI = 68 - 25 = 43\,\%$$

$$I_c = \frac{68 - 40.67}{68 - 25} = 0.636 \qquad \& \qquad I_L = \frac{40.67 - 25}{68 - 25} = 0.364$$

(6) An undisturbed saturated specimen of clay has a volume of 18.9 cm^3 and a weight of 30.2 gm. After oven drying the weight reduces to 18 gm. The volume of the dry sample determined by mercury displacement is 9.9 cm^3. Determine the shrinkage limit, specific gravity, volumetric shrinkage and linear shrinkage.

Solution:

$$w_1 = \frac{30.2 - 18}{18} = 0.677$$

$$\therefore\ SL = 0.677 - \frac{18.9 - 9.9}{18} = 0.177 = 17.7\,\%$$

At Shrinkage limit :

$$\gamma_d = \frac{18}{9.9} = 1.818\ \ t/m^3$$

$$\gamma_d = \frac{G_s\,\gamma_w}{1+e} \quad \& \quad e \cdot S = G_s \cdot w \qquad (S=1)$$

$$1.818 = \frac{G_s}{1 + G_s\,(0.177)}$$

$$G_s = 2.69$$

$$V.S. = \frac{18.9 - 9.9}{9.9} = 0.91 = 91\,\%$$

$$L.S. = 1 - \left[\frac{1}{0.91 + 1}\right]^{\frac{1}{3}} = 0.194 = 19.4\,\%$$

(7) The in-situ density of a soil is determined using the sand bottle. The weight of the excavated soil is 1210 gm. The weight of the sand bottle before and after pouring sand into the hole is 7800 and 6587 gm, respectively. The weight of sand filling the cone is 300 gm, and its density is 1.47 gm/cm^3. Calculate the in-situ density. If the natural water content is found to be 11.7 %, find the in-situ dry density.

Solution:

$$\text{Weight of sand filling the hole} + \text{cone} = 1213 \text{ gm}$$

$$\text{Weight of sand filling the hole} = 1213 - 300 = 913 \text{ gm}$$

$$\text{Volume of sand filling the hole} = \frac{913}{1.47} = 621 \text{ cm}^3$$

$$\therefore \gamma_b = \frac{1210}{621} = 1.95 \text{ gm/cm}^3$$

$$\& \ \gamma_d = \frac{1.95}{1+0.117} = 1.74 \text{ gm/cm}^3$$

(8) A core cutter weighing 970 gm is driven into the ground. The weight of the cutter filled with soil is 2890 gm. Knowing that the cutter is 10 cm diameter and 13 cm high, find the in-situ bulk density.

Solution:

$$W = 2890 - 970 = 1920 \text{ gm}$$

$$V = \frac{\pi (10)^2}{4} \times 13 = 1021 \text{ cm}^3$$

$$\therefore \gamma_b = \frac{1920}{1021} = 1.88 \text{ gm/cm}^3$$

(9) To find the natural density of a soil, an undisturbed specimen weighting 368 gm is coated with wax. The weight of the coated specimen is 397 gm. When dropped in a jar filled with water, it displaced a volume of 238 cm^3. Knowing that the density of wax is 0.85 gm/cm^3, find the natural density of soil.

Solution:

$$\text{Weight of wax} = 397 - 368 = 29 \text{ gm}$$

$$\text{Volume of wax} = \frac{29}{0.85} = 34.12 \text{ cm}^3$$

$$\text{Volume of soil} = 238 - 34.12 = 203.88 \text{ cm}^3$$

$$\therefore \gamma_b = \frac{368}{203.88} = 1.8 \text{ gm/cm}^3$$

(10) The relative density of a sand backfill is required to be "dense". If the maximum and minimum void ratios of the sand are 0.93 and 0.44, respectively, find the lowest possible value of dry density of the backfill. Take G_s =2.65.

Solution:

For "dense" sand : D_r = 65 to 85 %

The minimum dry density correspond s to to the lower D_r :

$$\therefore 0.65 = \frac{0.93 - e}{0.93 - 0.44}$$

$$\therefore e = 0.6115$$

$$\therefore \gamma_d = \frac{2.65}{1 + 0.6115} = 1.64 \text{ t/m}^3$$

(11) Use the relation for the relative density to complete the following table :

Soil	$e_{max.}$	$e_{min.}$	e	D_r	Description
A	0.91	0.30	0.6		
B	0.86	0.41		0.71	
C	0.94		0.56	0.8	
D	0.9	0.45			Very loose

Solution:

Apply the relation :

$$D_r = \frac{e_{max.} - e}{e_{max.} - e_{min.}}$$

Soil	$e_{max.}$	$e_{min.}$	e	D_r	Description
A	0.91	0.30	0.6	0.51	Medium dense
B	0.86	0.41	0.54	0.71	Dense
C	0.94	0.465	0.56	0.8	Dense
D	0.9	0.45	< 0.83	< 0.15	Very loose

3.8 Problems

(1) The results of three specific gravity tests carried out on a sandy soil using the density bottle are given. Find the average specific gravity.

Test No.	1	2	3
Weight of density bottle (gm)	40.71	44.52	42.13
Weight of bottle + dry soil (gm)	71.62	76.41	75.68
Weight of bottle + soil + water (gm)	110.44	115.47	112.58
Weight of bottle + water (gm)	91.05	95.488	91.52

(2) A sieve analysis test was carried out on two soil samples A and B. The results are aes follows:

Sieve size (mm)		٣٨	١٩	١٠	4.8	2.4	0.4	0.2	0.075
% - finer	Sample (A)	100	96	87	78	61	22	12	9
	Sample (B)	100	100	100	100	100	90	42	0

Draw the grading curves. Comment on the grading of each sample. Find the effective diameter and uniformity coefficient of each sample.

(3) A soil sample consisting of particles of size ranging between 0.02 and 0.6 mm is dropped into a tank 8 m deep. Calculate the settling time range. Take $G_s = 2\ .69$ and $\mu = 0.01$ poise.

(4) Results of a hydrometer test on a clayey silt soil sample are given below. Draw the particle size distribution of the soil. Find the clay content.

Data :

Weight of sample used in sedimentation (W_d) = 33.5 gm

Specific gravity of soil (G_s) = 2.7

Dispersing agent correction (C_d) = 4

Meniscus correction (C_m) = 0.5

Time	Elapse time	Temp. oC	Hydrom. reading
9 : 00	0	18.5	-
	1	"	20.6
	2	"	19.2
	4	"	17.0
	8	"	16.2
	15	"	15.0
	30	18	12.8
10 : 00	1 h	"	11.0
11 : 00	2	"	10.2
13 : 00	4	17	8.6
17 : 00	8	"	7.1
9 : 00	24	19	4.8
9 : 00	48	19	4.3

Use the hydrometer calibration given in Fig. 3.7.

(5) A soil sample is thoroughly mixed with water and allowed to dry. The dry weight and volume are 348 gm and 200 cm^3 , respectively. Taking the specific gravity 2.7 , find the shrinkage limit.

(6) The plastic limit of a soil is 32 %, and its plasticity index is 38 %. When the soil is dried from its state of plastic limit, the volume change is 36 % of its volume at the plastic limit. Also, the corresponding volume change of the soil from the liquid limit to the dry state is 67 % of its volume at the liquid limit. Determine the shrinkage limit.

(7) A saturated soil has a water content of 42 %, and its shrinkage limit is 18 % . Find the dry volume of a sample of this soil weighing 287 gm. Take the specific gravity 2.7.

(8) The liquid and plastic limits of a soil are 66 % and 29 %, respectively. The natural water content is 34.2 %. Find the liquidity index. Draw the relation between the water content and liquidity index for this soil for water content ranging between the plastic and the liquid limits.

(9) The sand bottle is used for determining the in-situ density of soil. The following data are obtained in the laboratory:

(a) Determination of the weight of sand filling the cone :

Weight of sand + bottle before pouring (gm) = 9550
Weight of sand + bottle after pouring (gm) = 9105

(b) Determination of the bulk density of sand :

Volume of container (cm^3) = 1000
Weight of sand + bottle before pouring (gm) = 9940
Weight of sand + bottle after pouring (gm) = 8020

The following data are obtained in the field :

Weight of soil excavated from hole (gm) = 1676
Weight of sand + bottle before pouring (gm) = 9912
Weight of sand + bottle after pouring (gm) = 8145

Find the in-situ density. If the natural water content is 8.6 %, find the in-situ dry density.

(10) A soil sample coated with a thin layer of wax weighs 263 gm. When immersed in water it displaces a volume of 154 cm^3. The wax is peeled off and found to weigh 22 gm. The specific gravity of the soil is 2.7, and that of wax is 0.9. Find the bulk density of the soil. Knowing that the water content is 15.1 %, find the void ratio.

(11) The maximum and minimum dry densities of a sand determined in the laboratory are found to be 1.93 and 1.44 t/m^3, respectively. Knowing that the in-situ dry density of the sand is 1.72 t/m^3, find the relative density.

(12) A sandy soil sample has a moisture content of 7.3 % and bulk density 1.87 gm/cm^3. Laboratory tests indicated that the void ratios of the soil material in its loosest and densest states are 0.91 and 0.4, respectively. Calculate the relative density and degree of saturation of the soil. Take $G_S = 2.65$.

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